Applications of Barrier-bucket RF Systems at Fermilab

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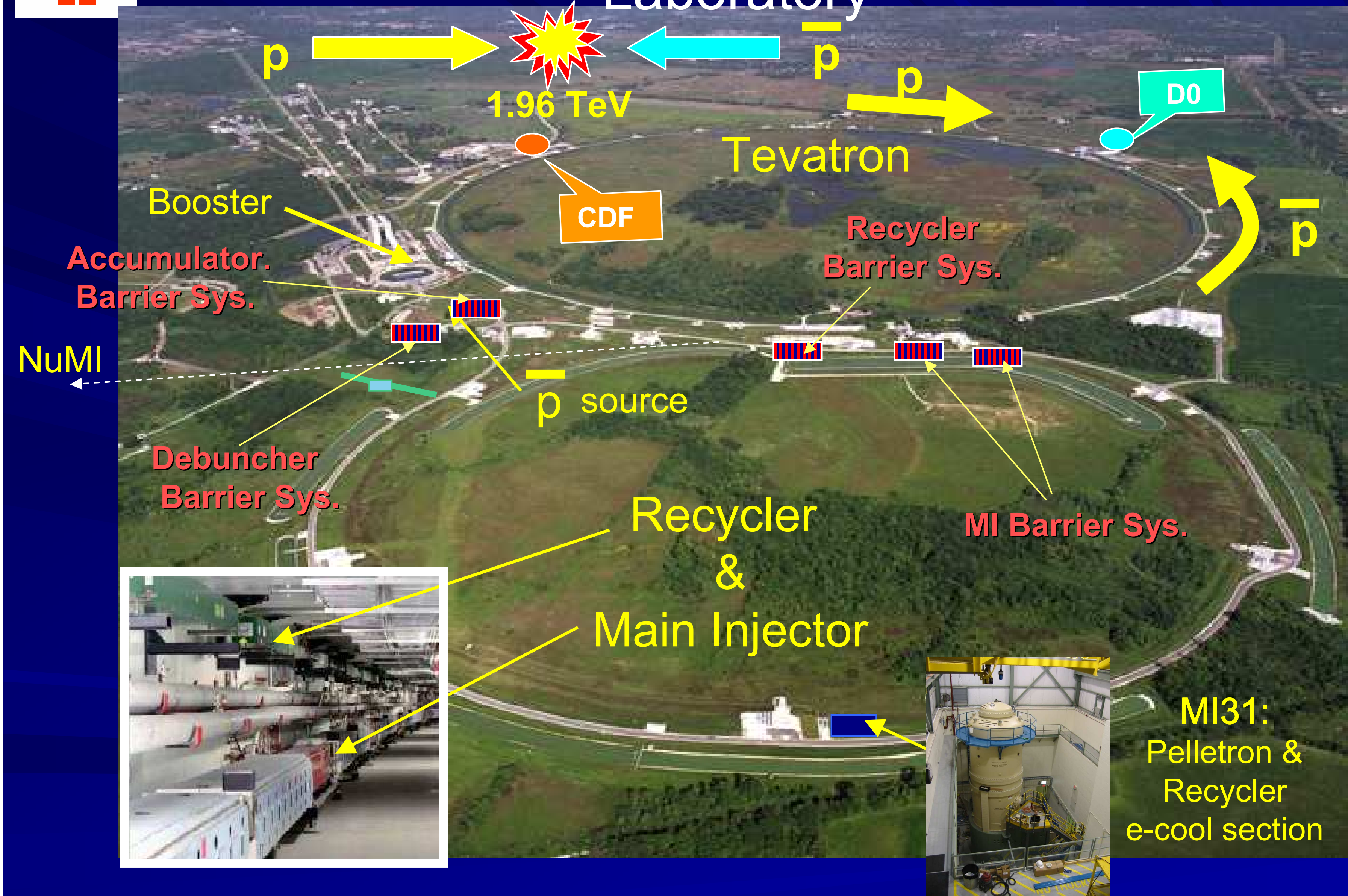
FERMILAB, the World's Pre-eminent HEP Laboratory



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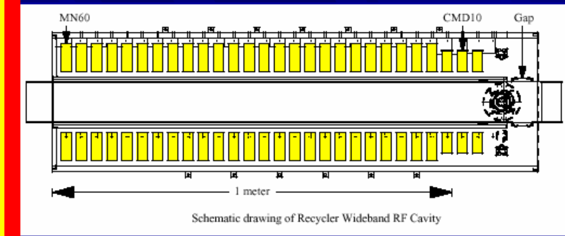
Recent Wide-band RF Systems

Barrier Cavities in the Recycler

Peak Voltage: 500V Power: 3.5kW
Type of Ferrite: Ceramic Magnetics MN60, CMD10
Shunt Impedance: 50 Ω /cavity
Band Width : 10kHz -100MHz
Dimension: ~ 1 meter
Cost: $75 k
Amplifier : Amplifier Research Model 3500A100
Cost: $150 k

PAC1999, p 869



Test Device in MI

Peak RF Voltage: 500V
Type of Ferrite: Not Known
Shunt Impedancd: 50Ω
Bandwidth ~50kHz-100MHz
Dimension= 1.5meter
Cost = not known

Main Injector Damper Cavities

Peak Voltage: 500V Power: 3.5kW
Type of Ferrite: 5 NiZn & 17MnZn Ferrite
Shunt Impedance: 50 Ω /cavity
Band Width : 10kHz -100MHz
Dimension: ~ 1 meter Cost: $75 k
Amplifier : Amplifier Research Model 3500A100
Cost: $150 k

D. Wildman
(private communications 2003)

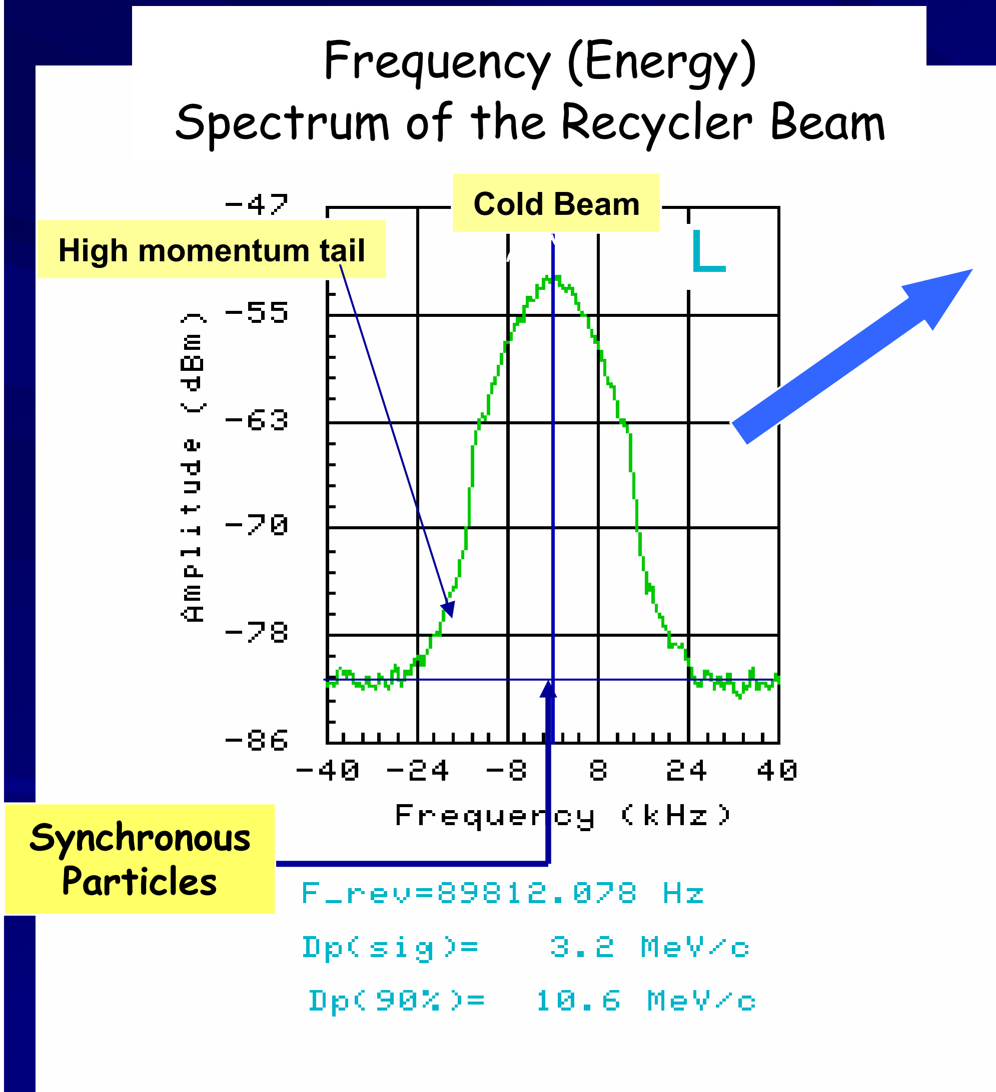
Main Injector Barrier Cavity

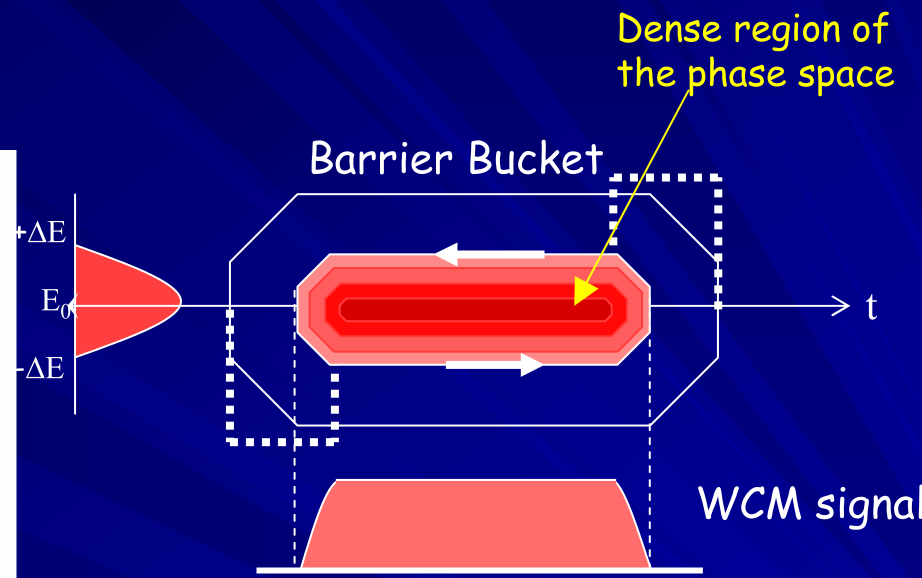
Peak Voltage: 10kV Power: 150kW
Type of Ferrite: 7 Finemet ® cores
Shunt Impedance: 500 Ω /cavity
Band Width : 50kHz -100MHz
Dimension: ~ 0.75meter Cost: $75 k
Amplifier : Switch
Cost: $40 k

D. Wildman
(private communications 2003)

Novel Beam Manipulation Techniques using Barrier RF systems for Collider Operation at Fermilab

Momentum Mining

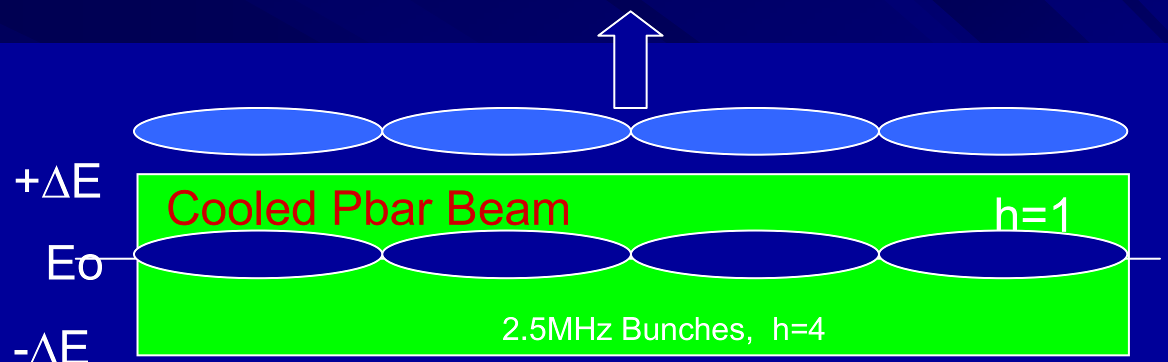


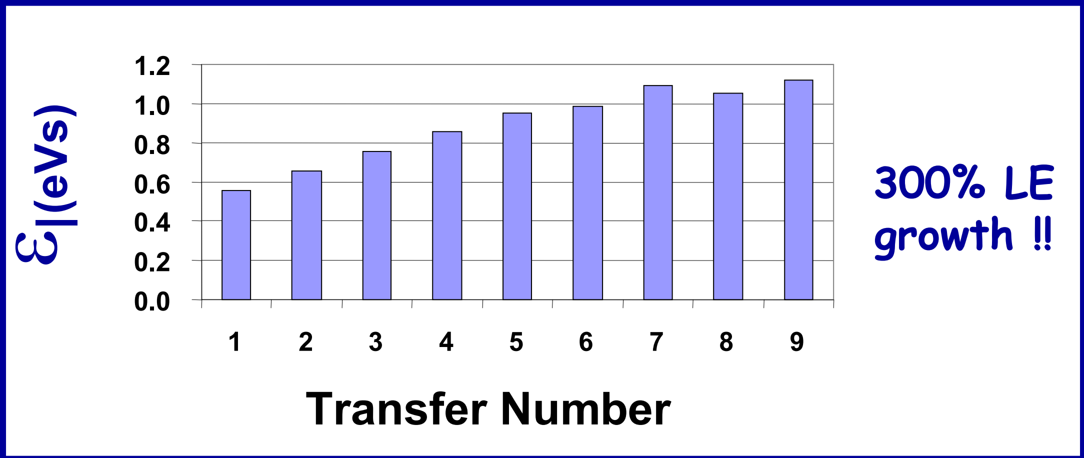


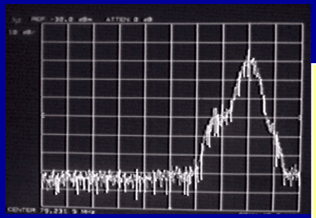
Is it possible to isolate the cold beam from the high momentum tail of a beam distribution without emittance growth and use only the cold beam and keep the leftover hot beam for further cooling?

Transverse Momentum Mining

(Current Mining Scheme at the Fermilab Accumulator)

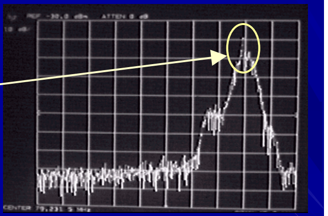


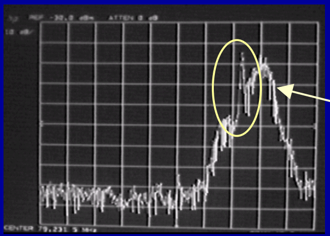




195E10 pbars
Cooled Beam
(12.7 eVs)

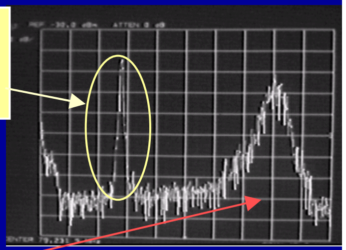
1st extraction from the core ≈ 3 eVs





Away from the core

Beam close to extraction orbit



174E10 pbars
12.4 eVs,22% growth

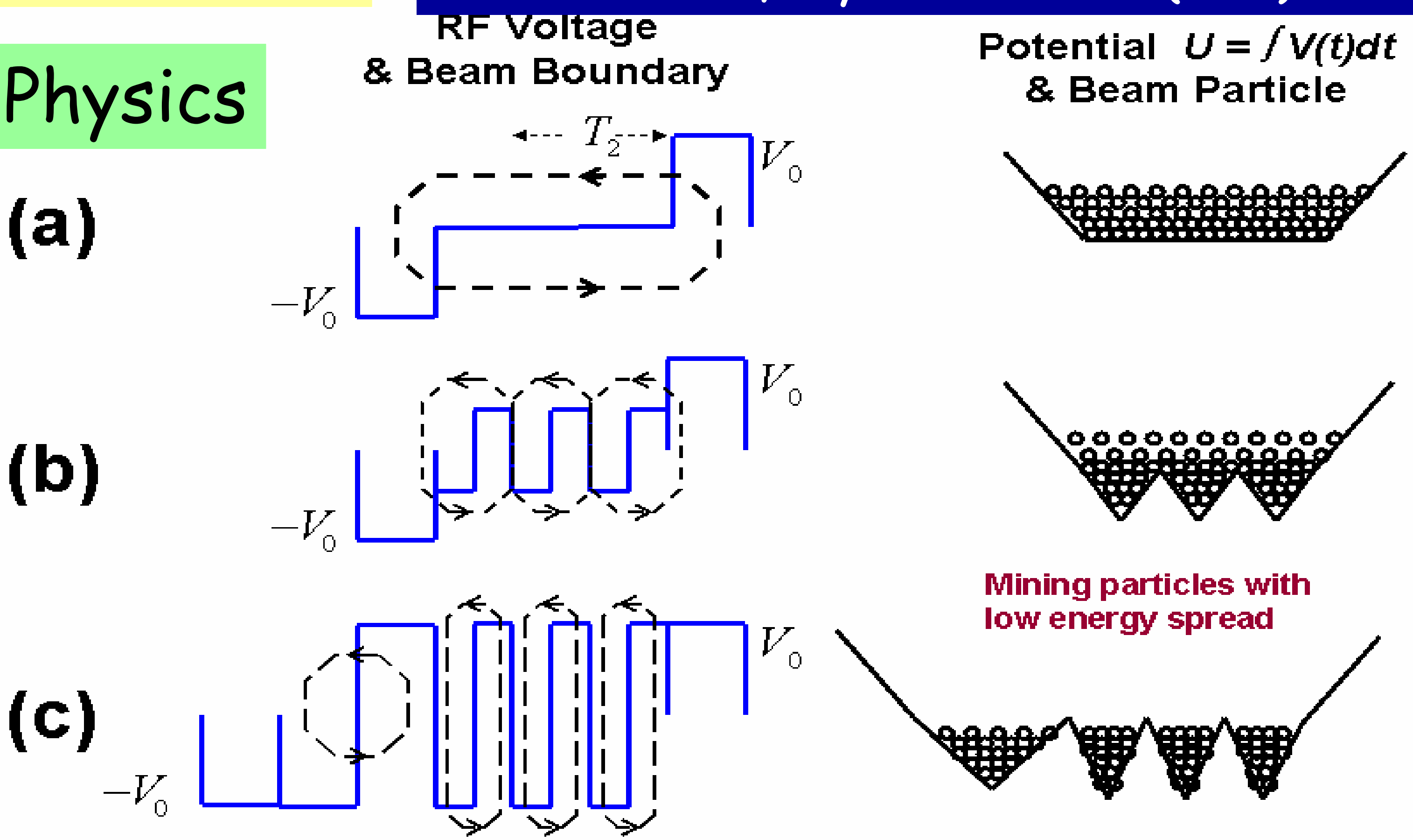
- **This was the method used in all hadron storage rings until recently**

Longitudinal Momentum Mining in a Synchrotron

New Technique

Ref: C. M. Bhat, Phys. Lett. A 330 (2004) 481

Physics



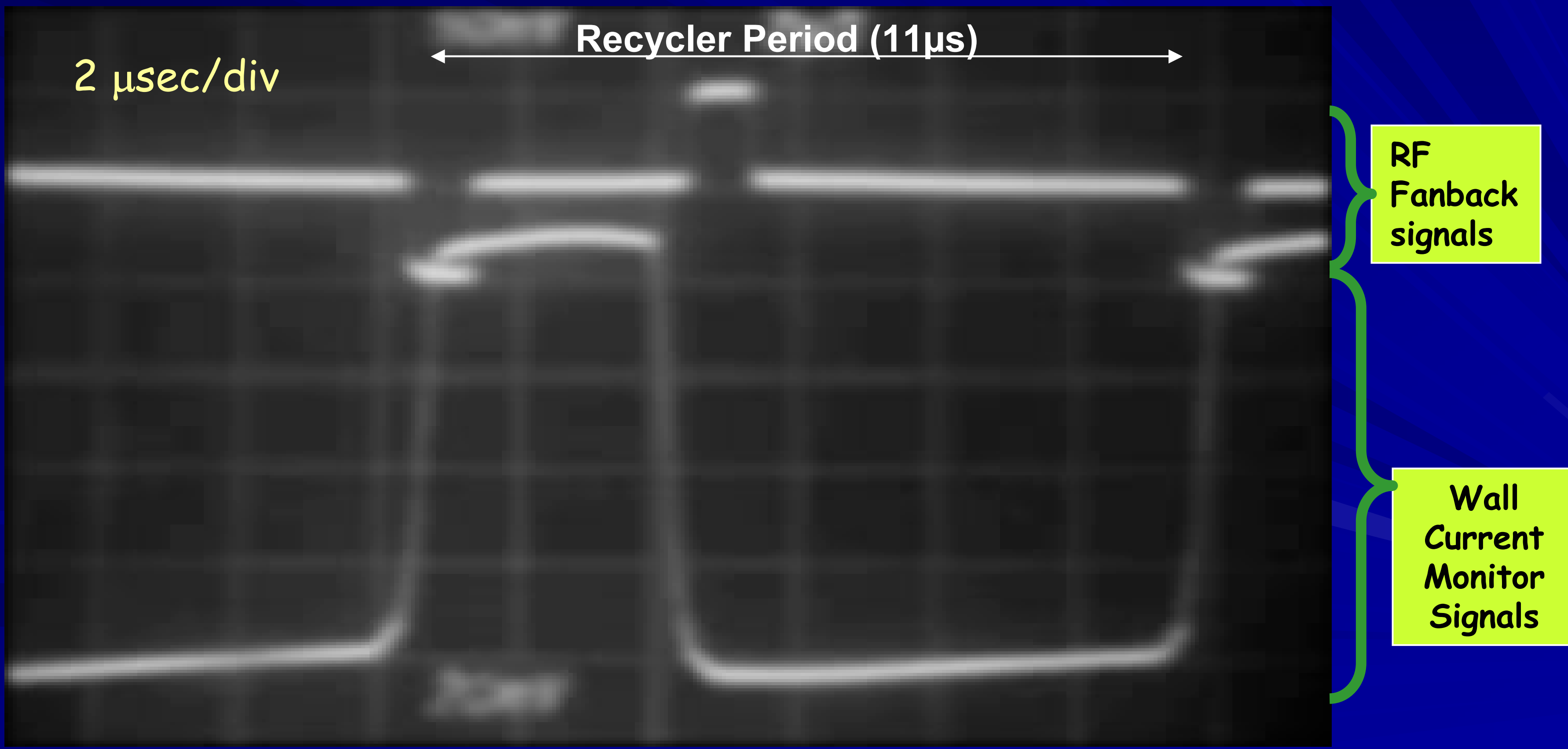
Technique is applicable to any storage ring for beam mining

Longitudinal Momentum Mining in the Fermilab Recycler

(proof of principle with protons)
Dec. 2003,

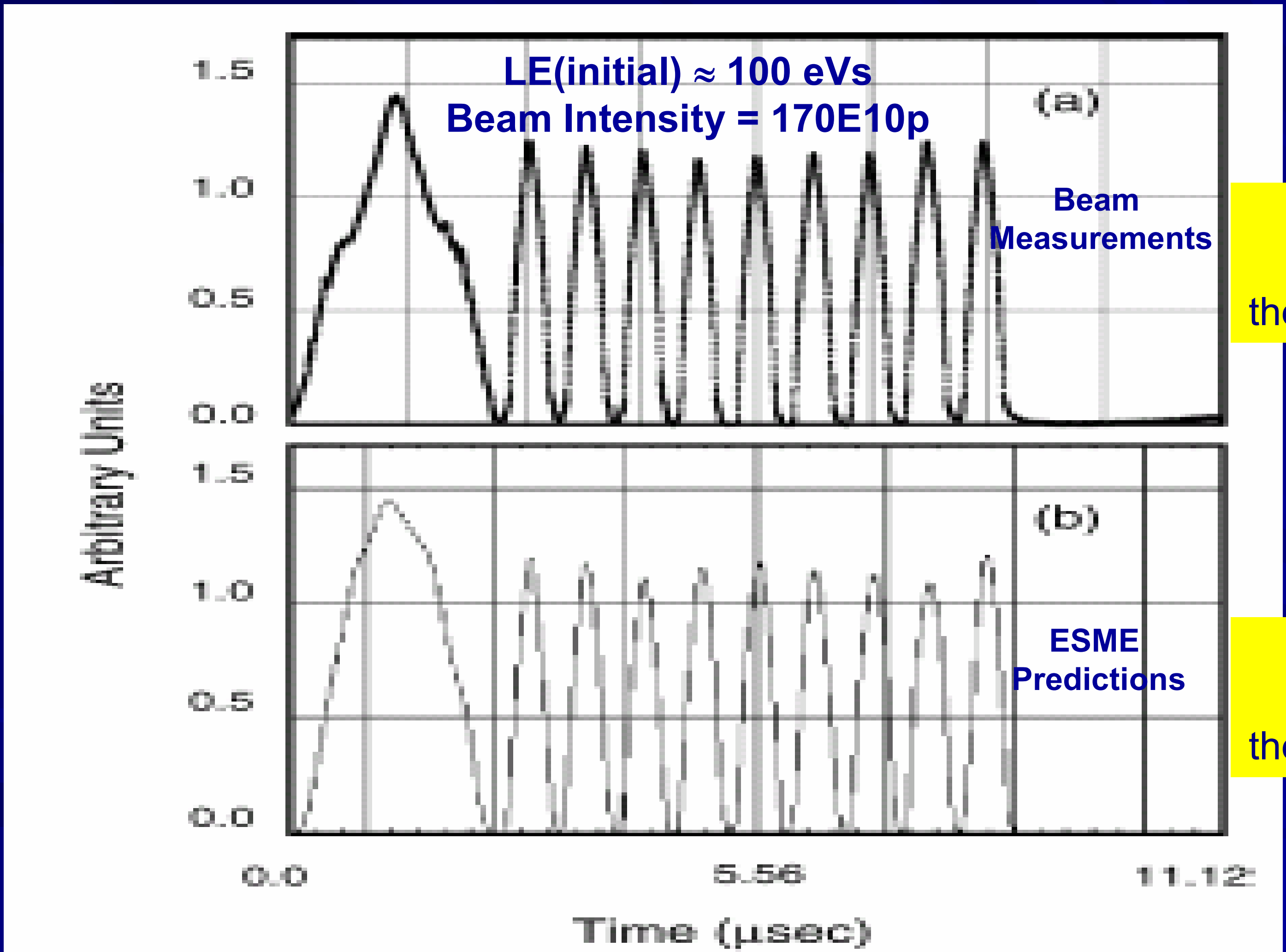
LE(initial) ≈ 100 eVs
Beam Intensity = 170E10p

Purpose: Mine 9x6 eVs= 54 eVs out
Equal intensity and LE bunches



A Comparison between Measurements and Predictions

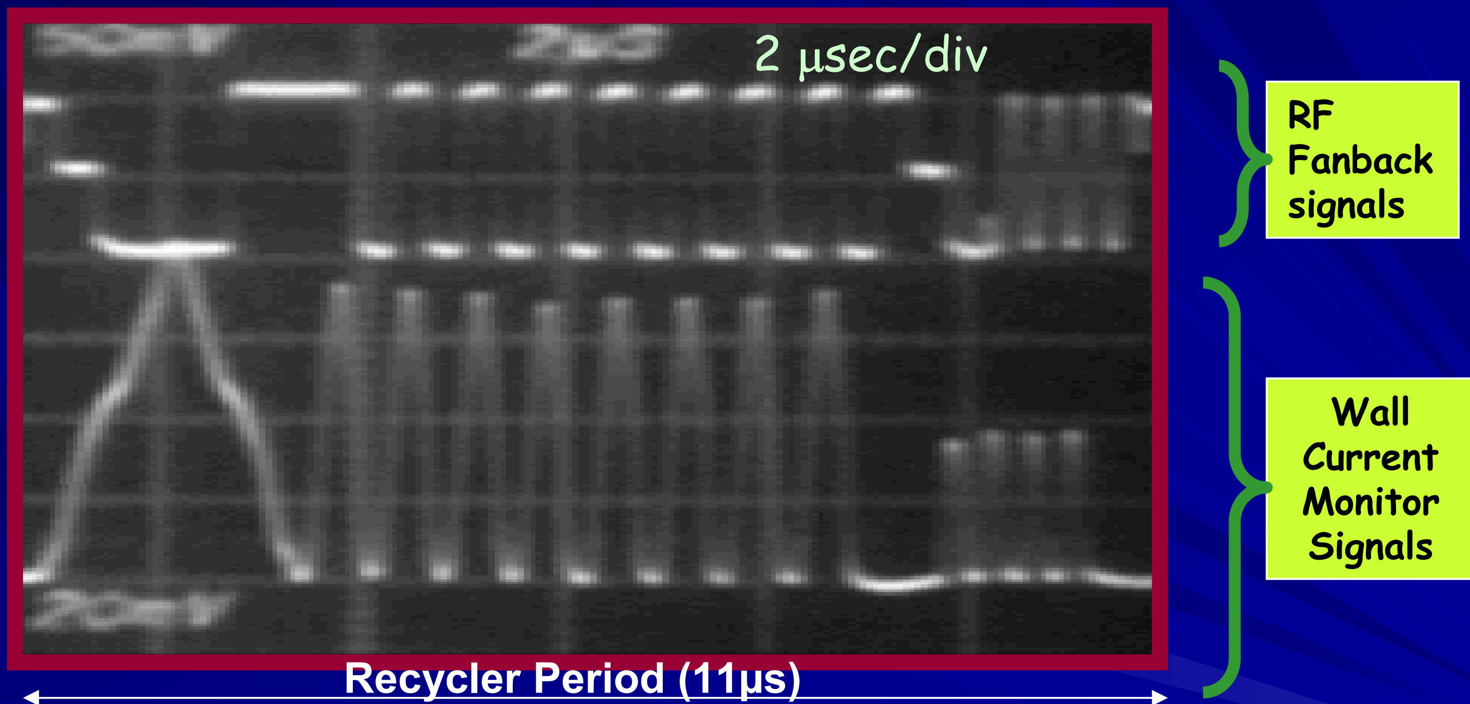
(First Beam Demonstration Dec. 2003)



Measured
65% beam in the mined buckets

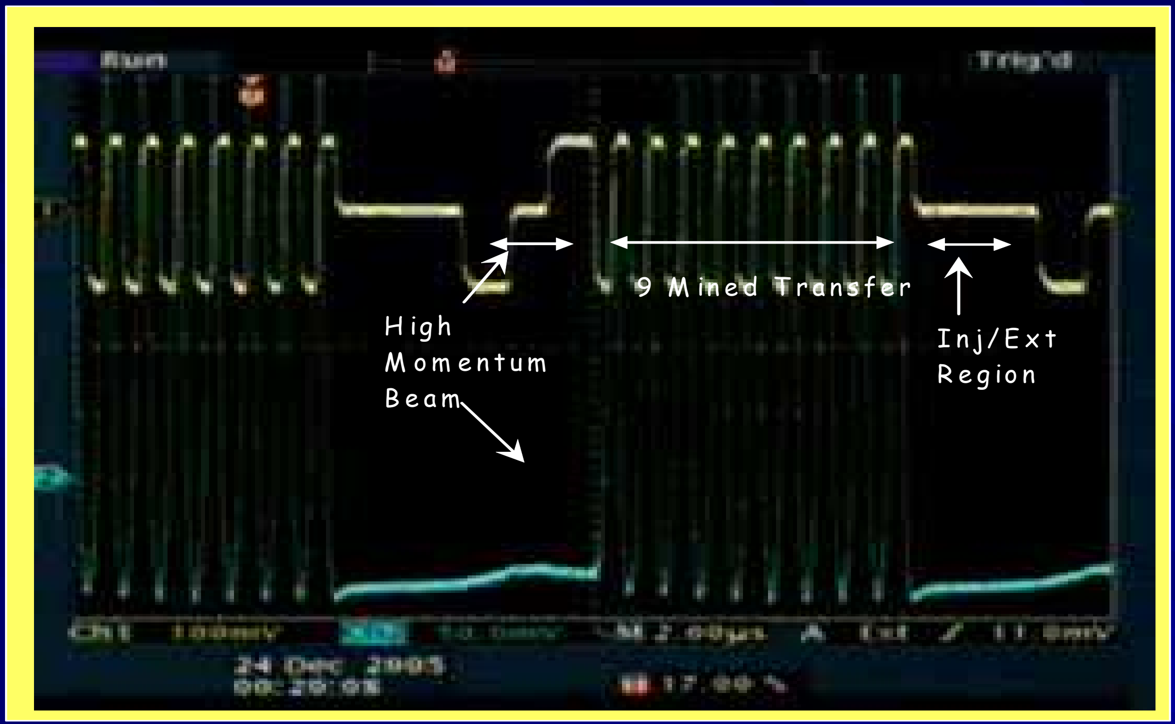
Predicted
74% beam in the mined buckets

Momentum Mining (cont.)
Tevatron Collider Shots



Early 2004 the longitudinal momentum mining was made operational.

Momentum Mining on e-cooled beam



Now we routinely inject up to about 97% of the pbars to the Main Injector from the Recycler

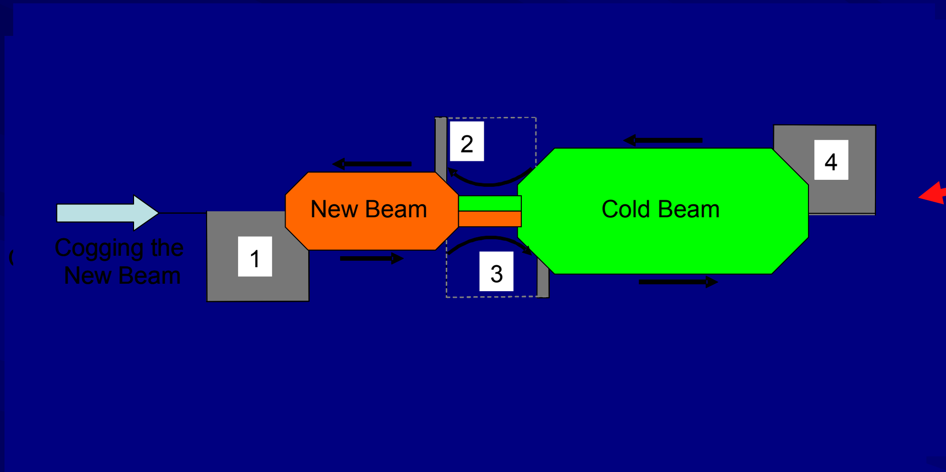
Imax(pbars) = 430E10
Goal = 600E10

Outcome – All of the ppbar collider stores in the Tevatron with initial L > 0.8 $\times 10^{32} cm^{-2} sec^{-1}$ came from longitudinal momentum mining in the Recycler.

The current world record ppbar L≈ 1.72 $\times 10^{32} cm^{-2} sec^{-1}$
Jan 6, 2006

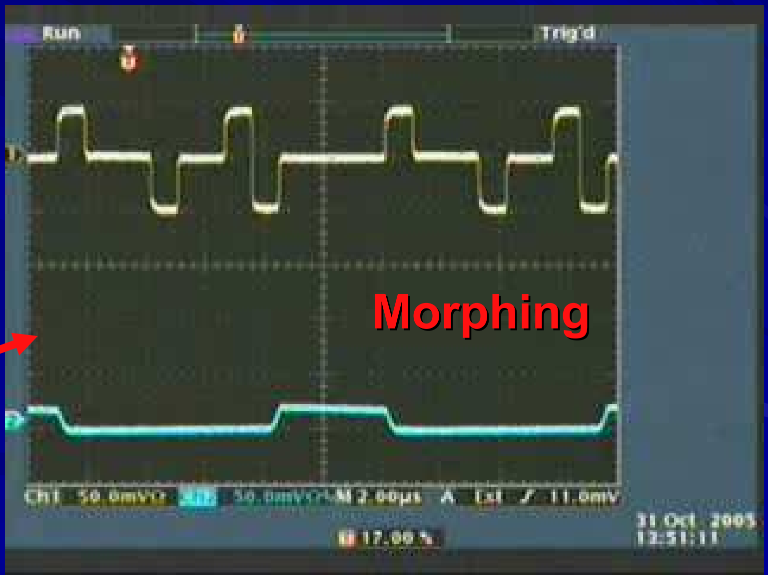
Pbar Stacking in the Recycler

(Video)



Pbar Stacking in the Recycler
Past (2001-2005)
C.M Bhat and John Marriner (2002)

~ 40% LE growth/transfer



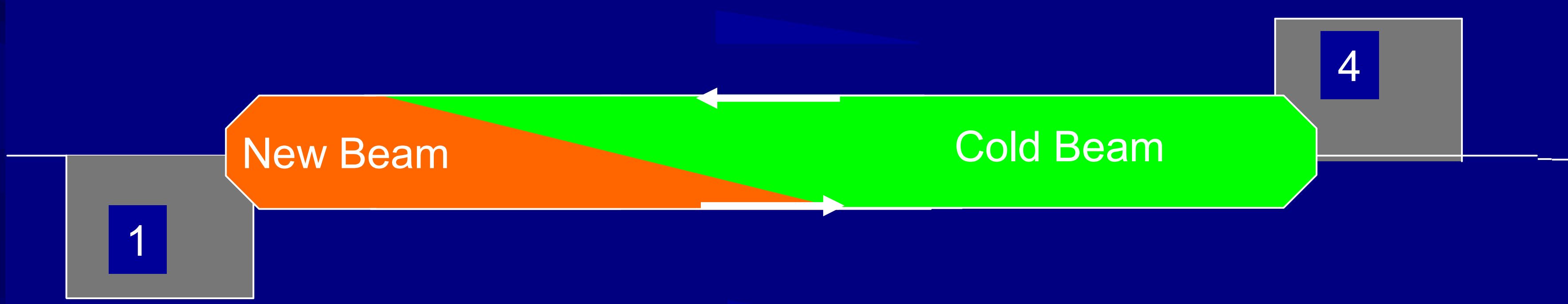
Present
Pbar Stacking in the Recycler
P. Joireman and B. Chase (Private Communications, 2005)

~ 10-15% LE growth/transfer

Iso-adiabatic pbar stacking for LE preservation

Motivation: To Preserve the LE better than 5%

C. M. Bhat, PAC05, p 1093



$$\varepsilon_A = C_1 T_A \Delta E_A + C_2 \Delta E_A^{\;3} + 0$$
$$\varepsilon_B = C_1 T_B \Delta E_B + C_2 \Delta E_B^{\;3} + 0$$

&

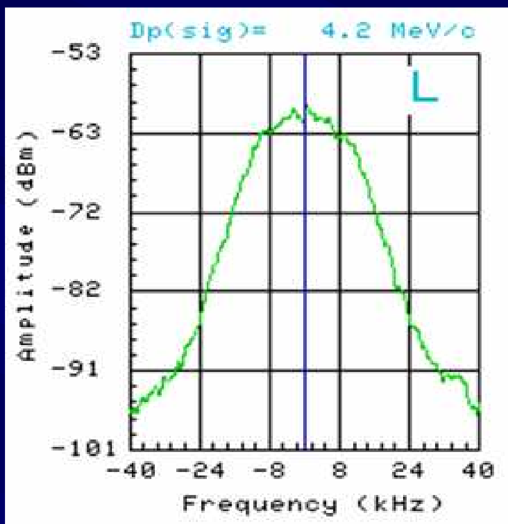
$$\delta T_A = -\delta T_B$$
$$\Delta E_A^{\;final} = \Delta E_B^{\;final}$$

gives

$$\delta T_A = \left[\frac{(\Delta E_B - \Delta E_A)(C_1 T_A + 3C_2 \Delta E_A^{\;2})(C_1 T_B + 3C_2 \Delta E_B^{\;2})}{C_1 \Delta E_B (C_1 T_A + 3C_2 \Delta E_A^{\;2}) + C_1 \Delta E_A (C_1 T_B + 3C_2 \Delta E_B^{\;2})} \right]$$

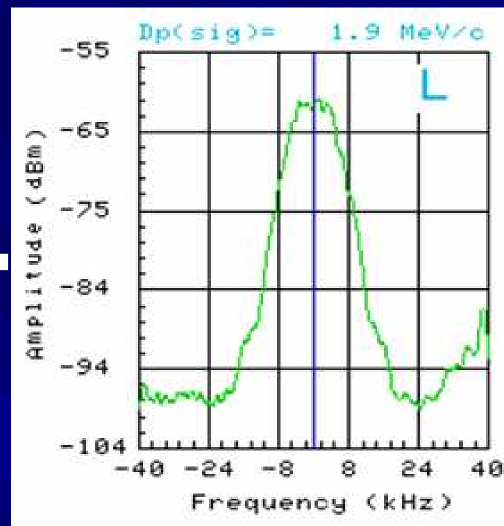
Iso-adiabatic Stack Merging

Demonstration in the Recycler



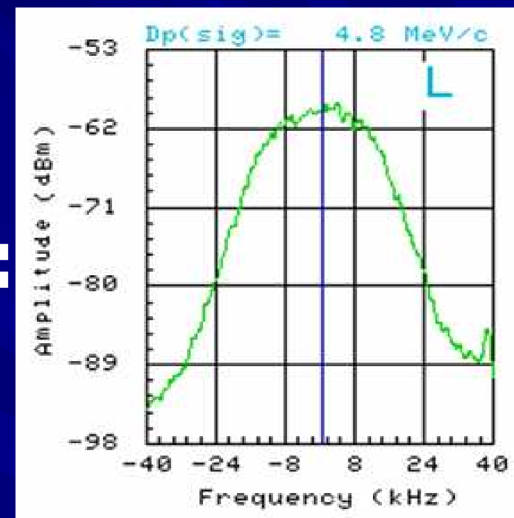
Old Stack
T=101 bkt
$\langle\Delta E\rangle_{rms}$ = 4.2 MeV
LE(95%) ≈ 35.5 eVs

+



New Stack
T=84 bkt
$\langle\Delta E\rangle_{rms}$ = 1.9 MeV
LE(95%)≈12.2 eVs

=



After Merging,
T=119 bkt,
$\langle\Delta E\rangle_{rms}$ = 4.8 MeV
LE(95%) ≈ 48.3 eVs

~2% LE Growth

All of the previously explained stacking methods

Disturb the Cold Beam significantly

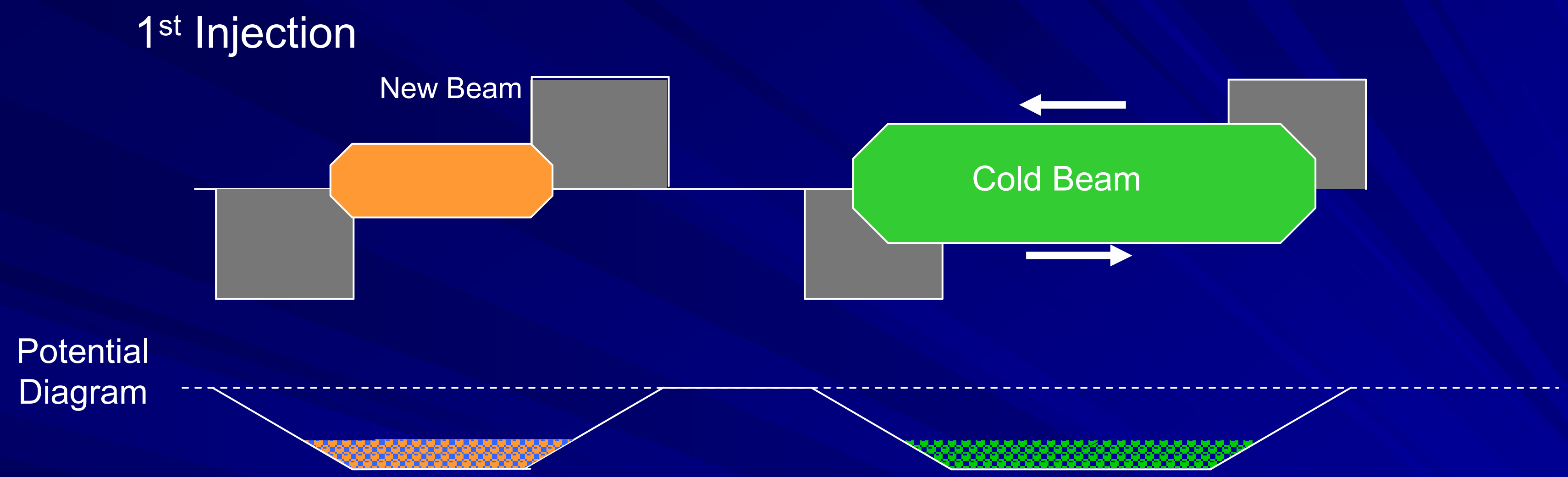
Hence

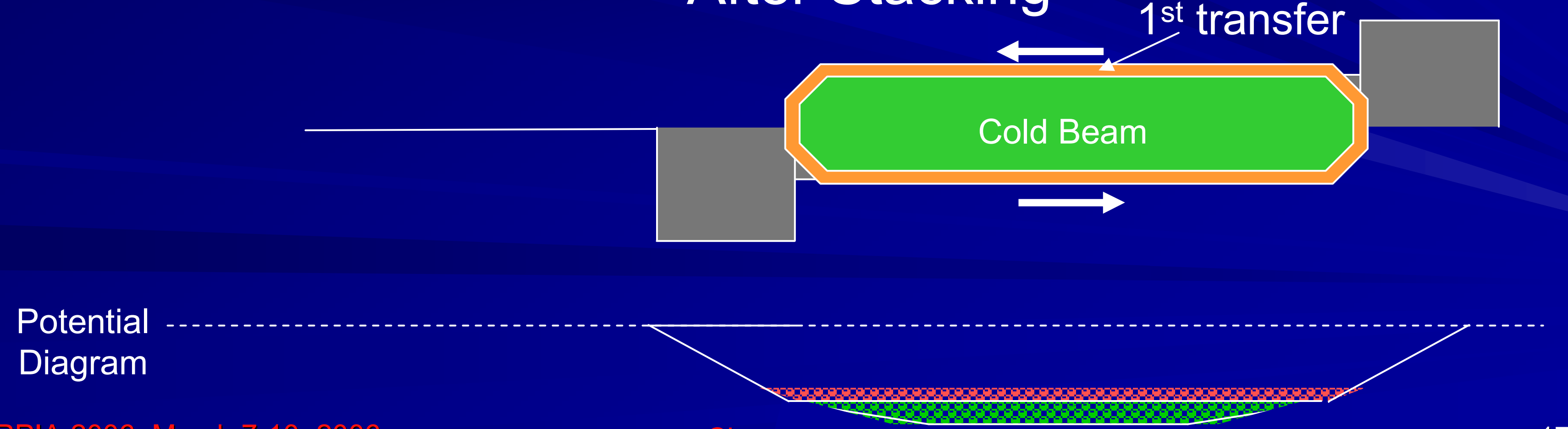
Longitudinal Phase-Space Coating

New technique

Longitudinal Phase-space Coating

C. M. Bhat, Beams-doc-2057-v1 (Dec. 2005)

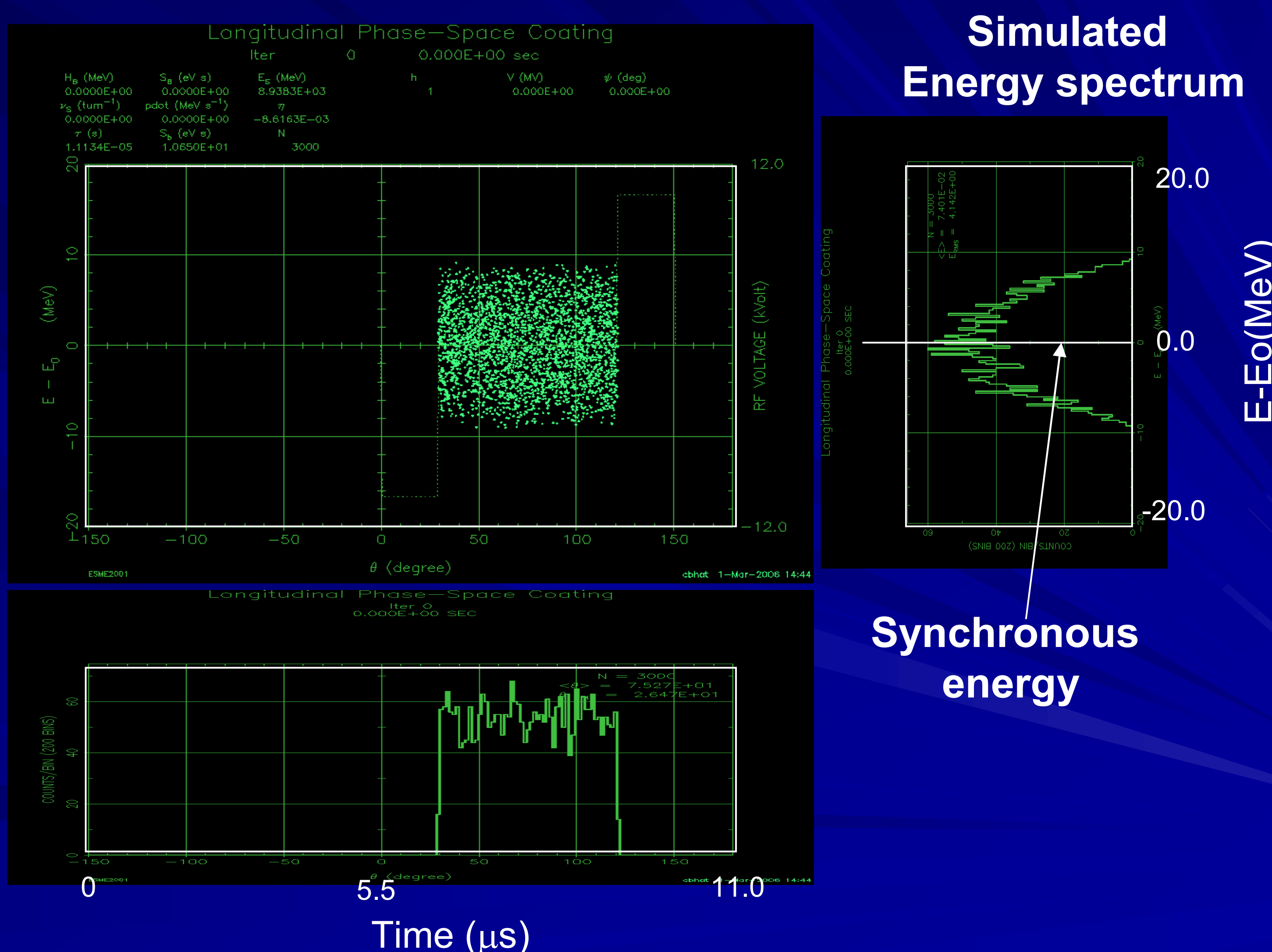




Simulations of Phase-space Coating

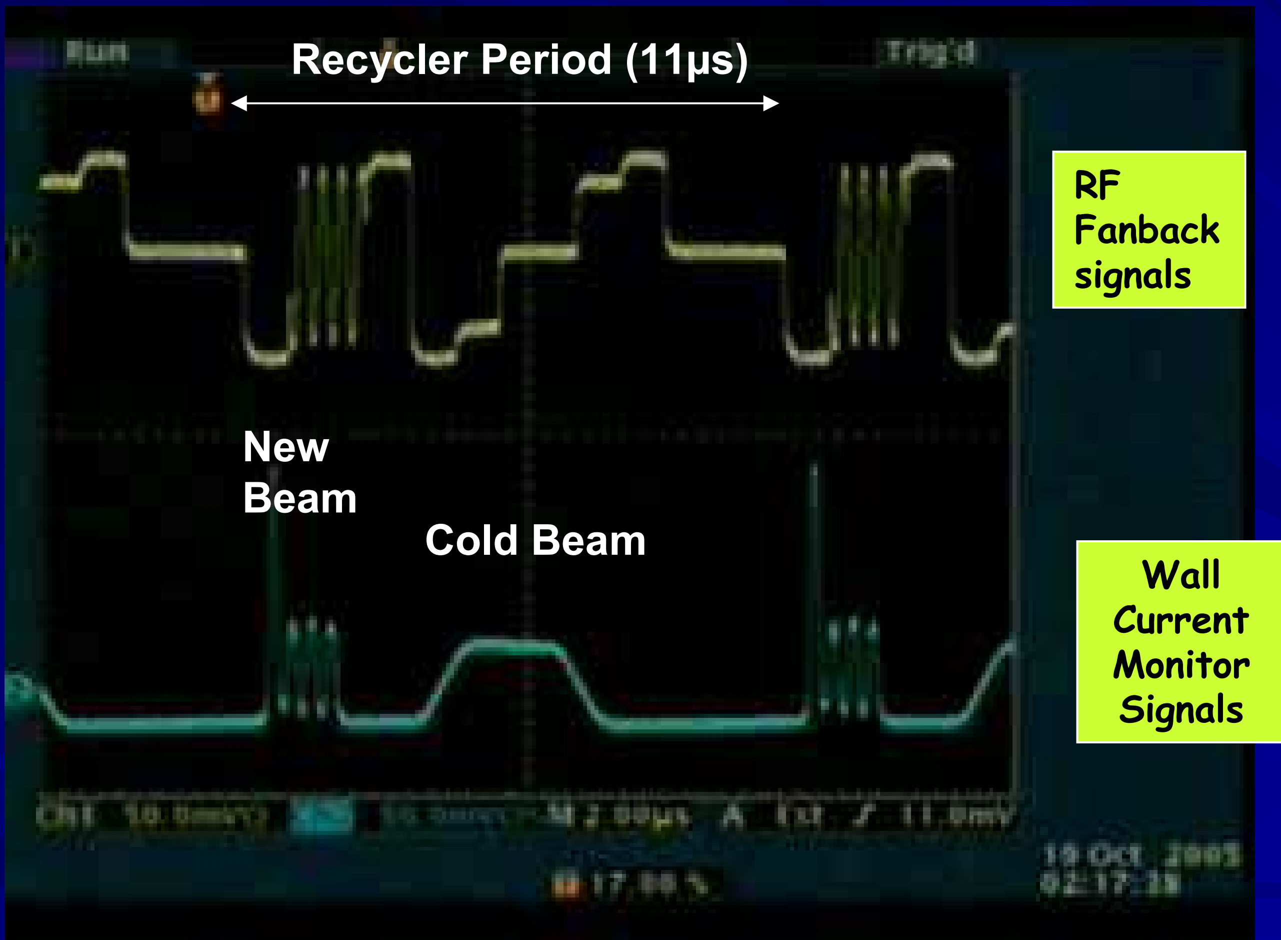
Phase-space distribution

Simulated WCM data

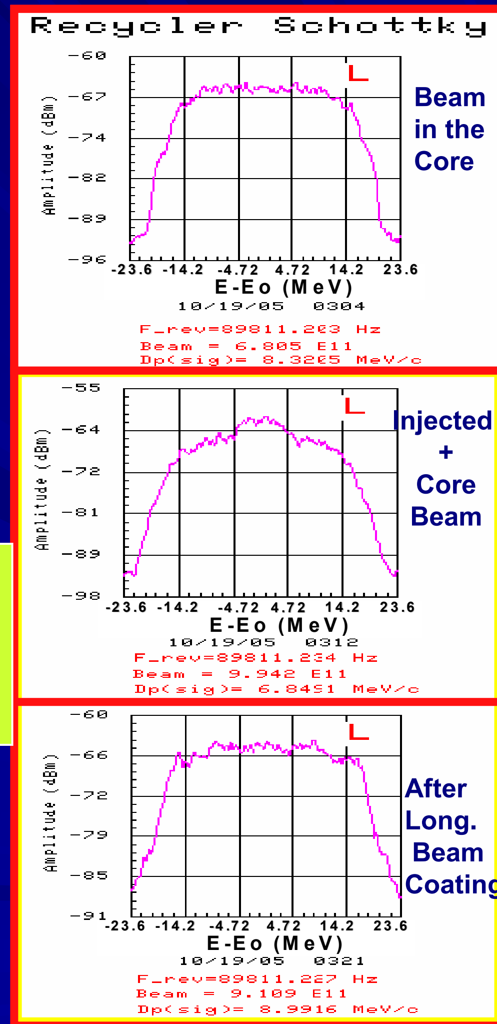


Experimental Demonstration of Longitudinal Phase-space Coating

(Video)



Schottky Spectrum

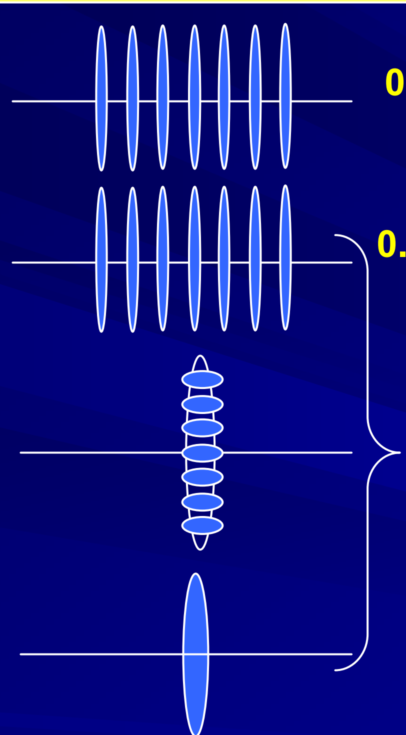


Work in progress

Bright Proton Bunches for Tevatron to increase ppbar Luminosity (future)

Current Proton Bunch Coalescing Scheme in the Main Injector

8GeV 53MHz Beam → 150GeV (BC) 53MHz bunches → 150 GeV (AC) 53MHz bunches → 150 GeV Bunch to Tevatron



0.15 eVs /53MHz Bunches

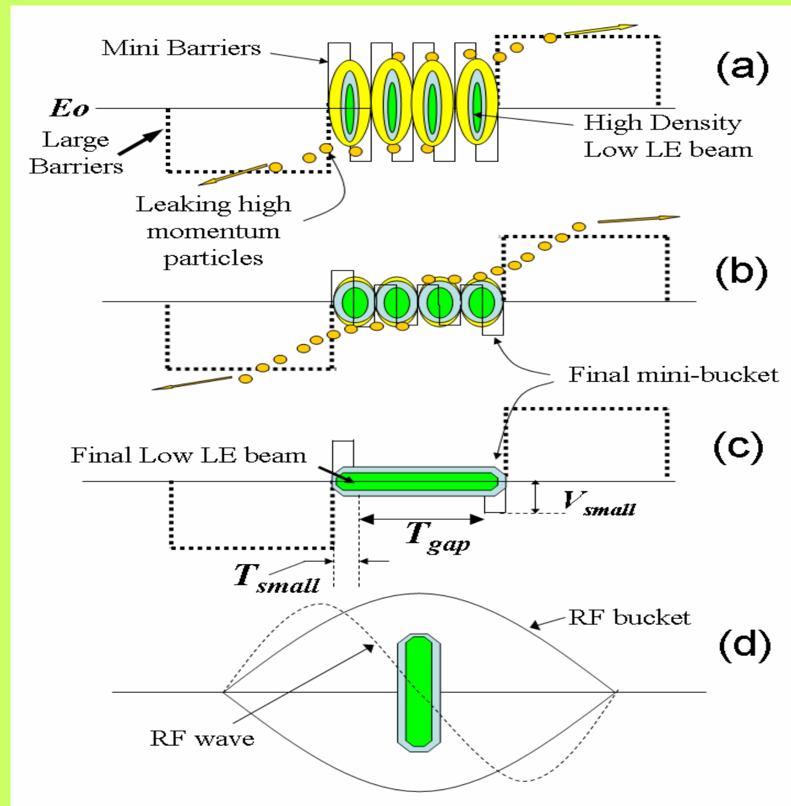
0.15 eVs /53MHz Bunches

~2.8E11p/bunch, LE ~ 3 eVs
Trans. emit.~16-20pi from MI

Beam in the Tevatron at collision
~2.4E11p/bunch, LE ~ 4 eVs
Trans. emit.~16-20pi

Proposed Barrier Proton Coalescing

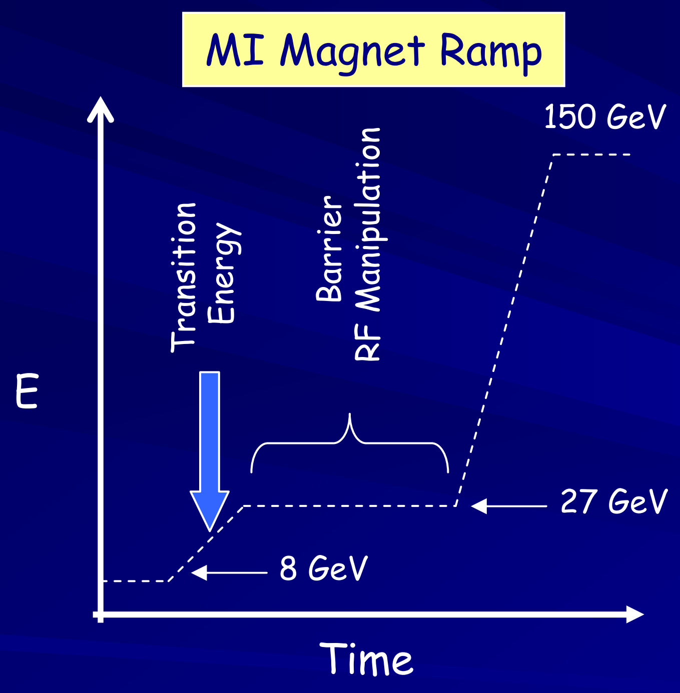
C.M. Bhat, PAC05, p 1745

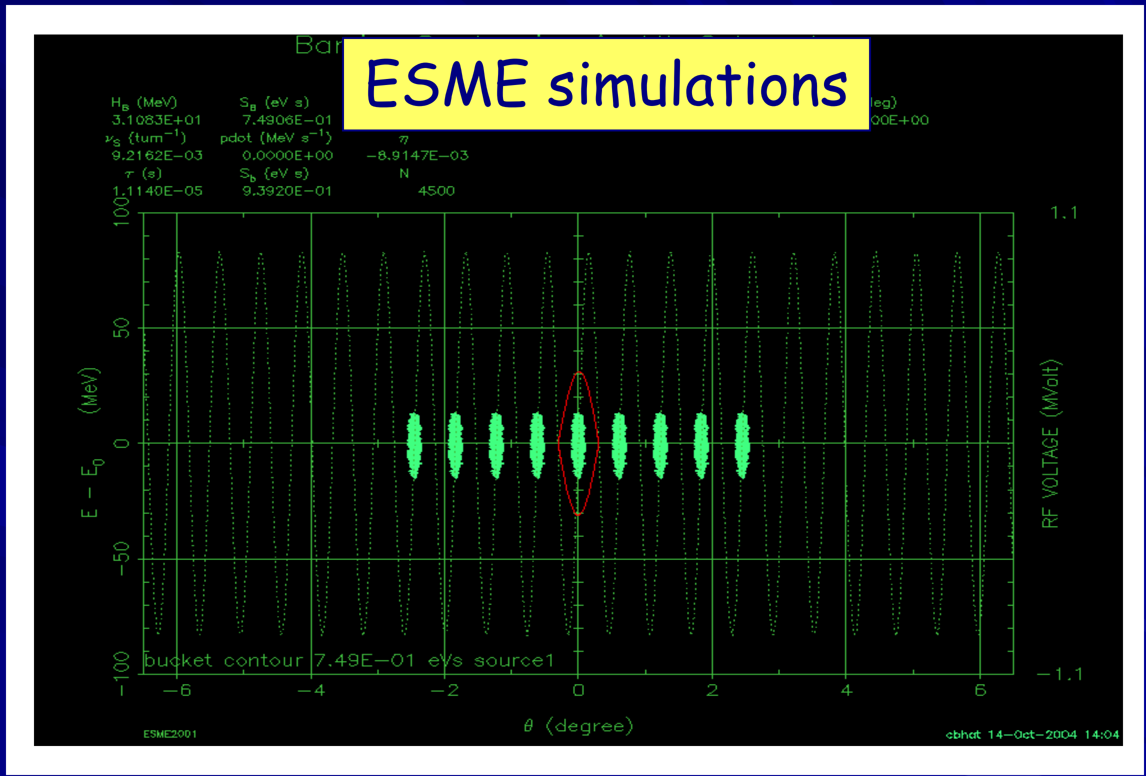


~3-4E11p/bunch
LE ~ 1.5-2 eVs
Trans. emit.~10-14pi

Bright Proton Bunches for Tevatron (cont.)

MI Barrier Coalescing





By this scheme one anticipates

- 50-100% lower longitudinal emittance proton bunches
- Better matching between p and pbar bunches
- Consequently,
  >25% increase in the collider luminosity

Other Applications

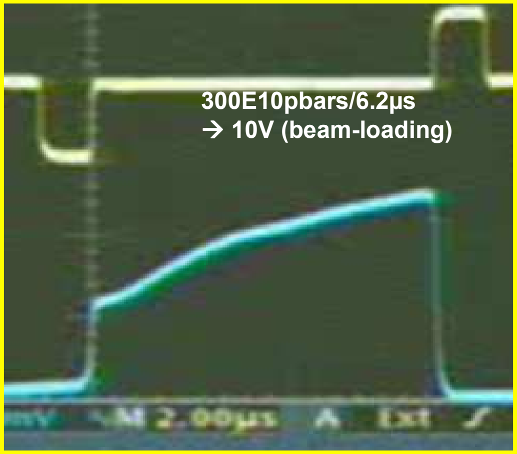
- High Intensity protons for the NuMI operation of the Main Injector
  - MI Longitudinal Dampers PAC2005, p1440 ← **in use**
  - Confining leaking beam during Slip-stacking and Injection Gap Clearing for NuMI (C. M. Bhat and D. Wildman, communications and PAC2005, p1189)
  - Fast Bunch compression EPAC04, page 1479 ← **Demonstrated**
  - Momentum Stacking (J. Griffin, Private communications, and PAC2003, 2922) ← **Studies are scheduled in summer 2006**
  - Iso-adiabatic bunch compression in the Main Injector PAC2005, p1189 ← **Demonstrated**
- More Recycler Applications
  - Gated stochastic Cooling in the Recycler EPAC04, p794 ← **Demonstrated**
  - Besetting the beam instability in the Recycler with sweeping anti-barrier bucket ←**proposed**

Challenges at High Intensity and at low Longitudinal Emittances

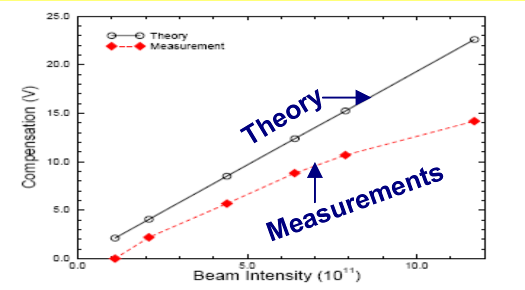
- Potential Well Distortion ← Beam loading effect

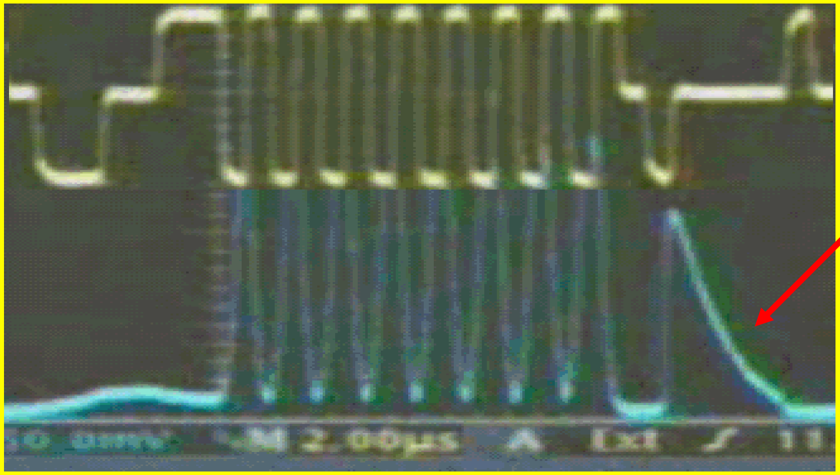
  C.M. Bhat and K.Ng Fermilab-Conf-03-395-T(Oct-2003)

- Asymmetry in the +ve and –ve barrier pulses ← $|V_-| > |V_+|$ (~2%)



We have seen potential well distortion at as low as 20E10 p/1.6us





- Higher Ordered harmonic Components in the baseline resulted in phase-space distortion

Summary

- Many Storage Rings at Fermilab use Barrier RF systems for varieties of beam applications.
- We have invented a number of Novel Beam Manipulation Techniques at Fermilab using Barrier RF systems. Operational implementation of some of them have already enhanced accelerator performance significantly. These methods can be applied at other accelerators.
- and there is more to learn …

Many More Applications to explored and Challenges to solve with Barrier RF systems